XXXIII. *Conductibility of Mercury and Amalgams.* *By* F. Crace-Calvert, *Esq., F.C.S., Mem. Roy. Acad. of Turin, &c. &c., and* Richard Johnson, *Esq., F.C.S., Mem. Phil. Soc. of Manchester. Communicated by Professor* Stokes, *Sec. R.S.*

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We have the honour to lay before the Royal Society the second part of our paper on the Relative Powers of Metals, Alloys, and Amalgams to conduct Heat. Having in our former paper described our experiments upon metals and their alloys, we now give the results obtained with mercury and amalgams.

The method followed in the investigations described in this paper is the same as that detailed in our former one. When the amalgams were solid, we melted and cast them in square bars, and filed them down until they were 1 c. m. square and 6 c. m. long; but when the amalgam was fluid, we introduced it into the small iron box (see former paper, Philosophical Transactions for 1858, p. 354) and determined its conducting power.

Before stating the results obtained with amalgams made of pure metals in equivalent and multiple quantities, we wish to draw attention to the remarkable manner in which heat is conducted by mercury.

But before entering into the details of our experiments, it is necessary that we should state that, having completed our researches some time since, we forwarded the results to the Junior Secretary, Professor G. G. Stokes, for presentation, when he kindly made to us the remark that mercury might be a worse conductor than we had found it to be, and that the means adopted by us were not sufficient to prevent the mass of mercury in the little iron box becoming heated through currents; and he suggested that we should tilt our apparatus, and ascertain what would be the influence of various angles on the conductibility of mercury as determined by our method.

By following out this suggestion, we were led to the interesting discovery that mercury is the worst conducting metal known, when the heat is so applied as to prevent the mass becoming heated by currents.

To attain this object, we filled our little iron box with pure mercury, and having ascertained by its weight that it was quite full, we introduced 1 cub. cent. of it into each of the vulcanized caoutchouc vessels; we then poured 50 cub. cent. of cold water, and waited until it had arrived at the temperature of the atmosphere of the laboratory. The larger vessel was in its turn filled with 200 cub. cent. of water at 90°. The apparatus was so arranged that the large vessel, or the source of heat, was placed perpendicularly over the small one. The temperature of the large one was maintained at 90° during

one quarter of an hour by a small jet of steam brought into it (for further details see the first part of these researches, page 350 of the Philosophical Transactions for 1858), when we obtained the following results:—

	Temperature of the 75 cub. cent. at beginning of experiment.	Temperature of 75 cub. cent. at end of 15 minutes.	Conductibility found reduced to 50 cub. cent. water.	Mean.	Silver 1000.
Mercury vertical...	14°·8 12·6	16°·0 13·7	1·80 1·65	1·7	54

We also tilted the apparatus and gave it gradually different angles, and the conductibility of heat by mercury gradually decreased as the angle increased, showing the following results:—

		Silver 1000.
At a slight angle	13·5	423
Angle slightly increased . .	7·3	229
Angle still more increased .	6·9	216
Considerable angle . . .	5·1	160

Lastly, the apparatus was used as in our former experiments, the little box being placed in a horizontal position, and the results agreed with those already published; for we obtained

	Mean.		Silver 1000.
21·6 21·8 21·5	21·63	or	679

There cannot therefore be a doubt that the supposed good conductibility of heat by mercury arose from not taking into account that mercury being a fluid, its facility to conduct heat was owing to currents. The same may be said of water; for we have observed, as is already known, that it presents a complete barrier to the conduction of heat when the source of heat is applied at the upper part of a column of water.

Thus in our experiments we have found that the temperature of the water in the lower vessel did not rise one-tenth of a degree during the quarter of an hour that the water in the upper vessel was maintained at 90° C.

The bad conductibility of heat by fluids when all currents are prevented in their mass, appears to us difficult to explain by the theories of undulation or radiation; for we cannot understand why the imponderable fluid caloric should not travel equally well between the molecules in whatever way the source of heat is applied, or why the undulations should not be as rapid, nay, more rapid in a fluid than in a solid. All these difficulties disappear if we adopt the views of Mr. J. P. Joule, F.R.S., which are, that heat is conveyed in bodies by the vibrations of the solid molecules composing them.

The remarkably low conducting power of mercury presents another point of interest, as it establishes a further analogy between heat and electricity. The ratio of conductibility of these two agents by mercury, as compared with that of silver, shows such close

relations when examined under the same volumes, that they deserve especial notice. Thus—

	Heat.	Electricity.
Silver	100·00	100·00
Mercury	5·33	2·12

On the Conductibility of Solid and Semi-solid Amalgams, or in which exists an excess of the Amalgamated Metal.

The amalgams belonging to this series were prepared with equivalent quantities of pure metals, and their conductibility for heat confirms the figure (54) which we now publish as representing the conductibility of mercury, silver being 1000. In fact the observed conductibility of heat by these amalgams agrees perfectly with the theoretical quantities, whilst there exists a great difference between them when we adopt 677 as representing the conductibility of mercury. The calculated numbers are obtained, as in the former paper (p. 358), by multiplying the conducting powers of the respective metals by the weights, and dividing by the sum of the weights.

Amalgams of Tin.

Formula of amalgams, and per-centages.	Exterior temperature.	Temperature of the 50 cub. cent. of water before experiment.	Temperature of the 50 cub. cent. of water after 15 minutes, from 5 to 5 minutes.	Found.	Mean.	Calculated, mercury being 1·7.
$HgSn_2$ Hg 45·88 Sn 54·12	15°·0 14·8	14°·5 14·6	18°·0 20°·8 23°·1 18·2 20·9 23·3	8·6 8·7	8·65	8·11
$HgSn_3$ Hg 36·18 Sn 63·82	15·0 15·0	15·1 15·5	18·9 21·9 24·5 19·4 22·3 25·0	9·4 9·5	9·45	9·2
$HgSn_4$ Hg 29·84 Sn 70·16	14·0 15·0	13·1 14·9	16·9 20·1 22·8 18·8 21·9 24·5	9·7 9·6	9·65	9·95
$HgSn_5$ Hg 25·38 Sn 74·62	16·0 16·0	14·9 15·11	19·1 22·5 25·2 19·4 22·8 25·4	10·3 10·3	10·6	10·5

Amalgams of Zinc.

Formula of amalgams, and per-centages.	Exterior temperature.	Temperature of the 50 cub. cent. of water before experiment.	Temperature of the 50 cub. cent. of water after 15 minutes, from 5 to 5 minutes.	Found.	Mean.	Calculated, mercury being 1·7.
$HgZn_2$ Hg 60·63 Zn 39·37	......	16°·0 15·3	19°·6 22°·8 25°·6 18·9 22·2 25·1	9·6 9·8	9·70	8·97
$HgZn_3$ Hg 54·70 Zn 45·30	......	16·1 17·1	19·7 23·4 26·6 20·9 24·5 27·5	10·5 10·4	10·45	10·05
$HgZn_4$ Hg 43·50 Zn 56·50	......	14·3 17·5	18·4 22·1 25·4 21·0 25·2 28·4	11·1 10·9	11·00	12·08
$HgZn_5$ Hg 38·11 Zn 61·89	......	17·1 16·2	22·6 27·2 31·0 21·7 26·3 30·2	13·9 14·0	13·95	13·05

Amalgams of Bismuth.

Formula of amalgams, and per-centages.	Exterior temperature.	Temperature of the 50 cub. cent. of water before experiment.	Temperature of the 50 cub. cent. of water after 15 minutes, from 5 to 5 minutes.			Found.	Mean.	Calculated, mercury being 1·7.
Hg Bi_2 Hg 31·82 Bi 68·18	15°·5	15°·2	16°·9	18°·4	19°·8	2·1	2·15	1·87
	15·5	15·3	17·1	18·5	20·0	2·2		
Hg Bi_3 Hg 23·86 Bi 76·14	15·0	14·8	15·7	16·6	17·4	2·6	2·6	1·89
	15·0	14·7	15·6	16·6	17·3	2·6		
Hg Bi_4 Hg 19·03 Bi 80·97	14·5	14·9	15·8	16·7	17·5	2·6	2·55	1·90
	14·8	15·0	15·8	16·6	17·5	2·5		
Hg Bi_5 Hg 15·82 Bi 84·18	13·0	13·6	14·35	15·2	15·9	2·3	2·35	1·91
	13·5	13·4	14·25	15·1	15·8	2·4		

On Amalgams which contain an excess of Mercury.

These amalgams, also prepared in equivalent quantities, were all fluid, owing to the circumstance that the proportions per cent. of mercury predominated over those of tin, zinc, and bismuth. The conduction of heat by these amalgams was therefore determined in the small iron box placed perpendicularly, and the source of heat applied at the upper part of the column; and this mode of operating has led us to observe the curious and interesting fact, that all this class of amalgams have the same, or nearly the same, conducting power, viz. from 1·9 to 2·3, although the proportions of tin vary in them from 10·52 to 22·98; those of zinc from 6·09 to 13·97; and those of bismuth from 17·55 to 34·73.

All the results obtained with these amalgams being within the limits of 1·9 to 2·3, we think it useless to give the details of the experiments.

Conductibility of Compound Bars.

In our former paper we described some experiments which we had made with bars composed of small cubes of copper soldered alternately with cubes of zinc, tin, and lead, having 1 c. m. of surface, and we showed that such compound bars conducted heat as indicated by theory. Since then we have pursued our researches, and have found that when compound bars are made of cubes of copper and bismuth, or of copper and antimony, then they conduct heat no longer in relation with the calculated numbers, as for instance—

		Found.	Calculated.
No. 1 bar	3 cubes of Copper, 1 cub. cent. 3 cubes of Antimony, 1 cub. cent.	9·45	17·32
No. 2 bar	3 cubes of Copper, 1 cub. cent. 3 cubes of Bismuth, 1 cub. cent.	3·40	13·25*.

* *Note added during printing.*—These numbers were calculated in the same manner as in the case of

It will no doubt be remembered that we also experimented upon bars which, instead of being composed of cubes, were made of two longitudinal bars of copper, juxtaposed and soldered to two other longitudinal bars of either tin, zinc, or lead, and that all these bars conducted heat as if they had been entirely composed of pure copper, and had not contained half their bulk of tin, zinc, or lead. We have made, since those results were published, a great number of experiments with the hope of throwing some light on the above interesting fact, but we regret to say without success. We have, however, noticed a result which deserves to be recorded; it is, that a bar composed of 2 of bismuth and 2 of antimony, juxtaposed and soldered together, is the only one which conducts heat in the same ratio as indicated by theory; for example,—

	Found.	Calculated.
No. 3 bar $\left\{\begin{array}{l}\text{2 bars of Bismuth}\\ \text{2 bars of Antimony}\end{array}\right\}$	3·90	3·63

We have also ascertained that the fine film of solder existing between the blades exerts no influence whatever on the proportion of heat conducted by the compound bars, for we have—

No. 4 bar soldered $\left\{\begin{array}{l}\text{2 of Copper}\\ \text{2 of Zinc}\end{array}\right\}$ gives 26·85.

No. 5 bar, in which gutta percha was employed to keep together the four small blades . . $\left\{\begin{array}{l}\text{2 of Copper}\\ \text{2 of Zinc}\end{array}\right\}$ gives 26·35.

alloys (see page 833). It has been pointed out to us that in the case of the bars composed of different metals placed end to end, the theory of the conduction of heat leads to the following simple result:—the resistance of the whole bar, multiplied by its length, is equal to the sum of the specific resistances of the separate metals multiplied by their respective lengths, the resistance being measured by the reciprocal of the conductibility. This gives for the conductibilities of the bars Nos. 1 and 2, the reciprocal of the mean of the reciprocals of the conductibilities of the two component metals. Taking the numbers given in the former paper, copper (rolled) 26·95, antimony (mean of two) 6·485, bismuth 1·95, we thus find for bar No. 1, 10·45, for No. 2, 3·64, which do not greatly differ from the numbers given by experiment.